MAGNETIC AND TRANSPORT PROPERTIES OF THE RARE-EARTH INTERMETALLIC COMPOUND $PrAl_2$

S. A. Mahmoud
Physics Department, Faculty of Science,
Alexandria Univeristy

Abstract

Low temperature (4.2 – 80 K) measurements on the thermal conductivity of the rare-earth intermetallic compound $PrAl_2$ are reported. The magnetic part of the resistivities of crystal electric field effects (CEF) is the matter of interest. For this purpose, the isostructural compound $LaAl_2$-is used as the non-magnetic counter part of $PrAl_2$. The measurements show evidence of (CEF) effects on transport properties of the rare-earth intermetallic compound $PrAl_2$ containing magnetic ions.

Introduction

The intermetallic rare earth compound $PrAl_2$ belongs to the cubic Laves phases with C-15 structure of the $MgCu_2$ type. The praseodymium ions are arranged in a diamond lattice and the aluminium ions are situated in the tetrahedral inerstices of this diamond lattice. Thus the praseodymium ions are under the influence of a crystalline electric field (CEF) of cubic symmetry. This CEF removes partly the degeneracy of the ground state of the 4f electrons and leads to the so-called CEF levels. The CEF ground state of $PrAl_2$ is nonmagnetic doublet. Therefore $PrAl_2$ should behave like a paramagnet. If the exchange interaction exceeds a certain threshold value, a ferromagnetic ordering can, however, occur [1].

In order to understand the nature of the crystalline electric field (CEF) containing rare-earth ions a variety of properties was studied [1,2,3]. We are interested in the magnetic part of the resistivities crystal-field effects. Here we report measurements of the thermal

[4,5] and electrical [6,7] conductivity of the intermetallic compound $PrA1_2$ at low temperature.

For this purpose, the isostructural compound $La1_2$ [5,6,7] is used as non-magnetic counter part of $PrA1_2$. The measurements show evidence of (CEF) effects on transport properties of the rare-earth intermetallic compound $PrA1_2$ containing magnetic ions.

Experimental

The polycrystalline samples of $PrA1_2$ for the measurements of thermal resistivities were 8.0 x 4.42 x 2.35 mm in size.

The thermal conductivity (γ) was measured in the temperature range 4.2 K and 80 K by the usual steady state method.* The absolute temperature and the temperature gradient across the sample were recorded simultaneously by gold (0.03% Fe) - chromel thermocouples with an accuracy of about 1 mk. The temperature of the sample holder was kept constant during the experiment by an automatic temperature control device.

Result and Discussion

Fig. (1a) shows the results of measurements on $PrA1_2$ where the thermal resistivity multiplied by temperature is illustrated. The experimental accuracy of the thermal resistivity is about 10%. It is clear that there is an anomalous behavior which can be attributed to the effect of (CEF) in $PrA1_2$.

According to Matthiesen's rule, the thermal conductivity in metallic materials is a sum of the contributions of different electrons scattering mechanisms. So the (CEF) is attributed to the scattering of the carriers through exchange and aspherical coulomb interaction with the localized 4f electrons [1,2,3]. To show the contribution of the magnetic part in $PrA1_2$, we have used the experimental values of Streglich [5] for the isostructural non-magnetic compound $LaAl_2$,

---

*** The measurements of thermal conductivity of $PrAl_2$ were done at the department of Physics, Technical University of Dresden - Germany.**

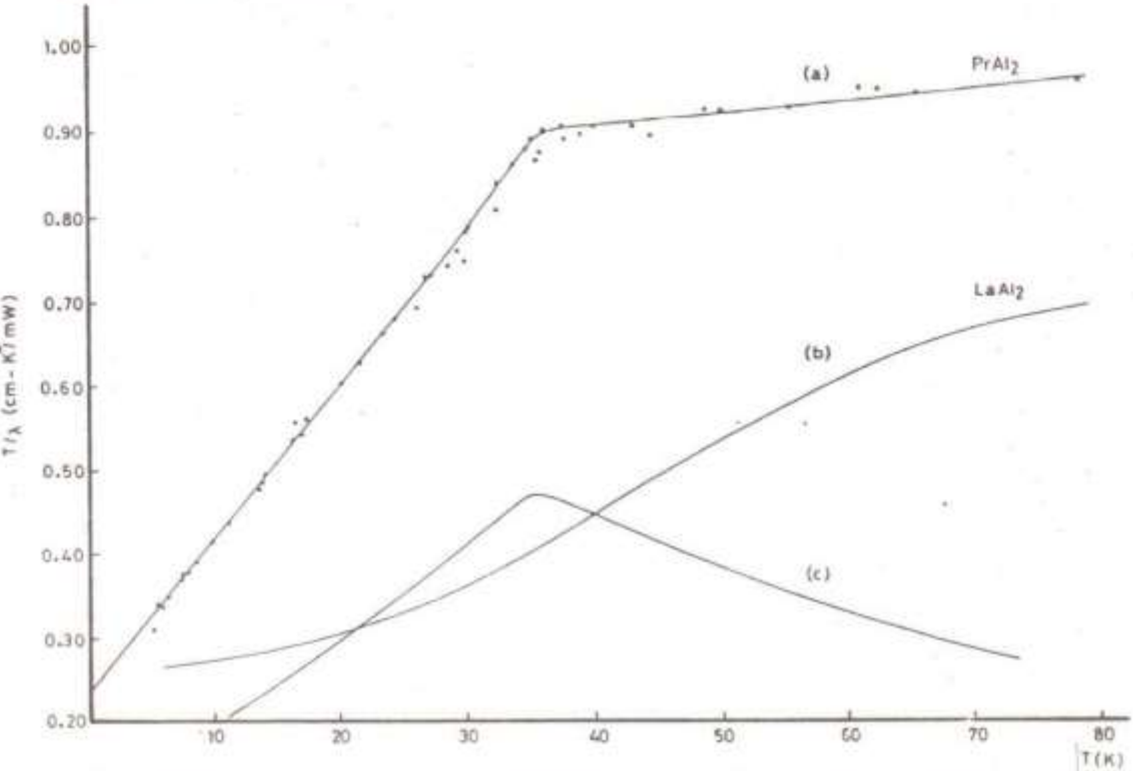

Fig 1-Thermal resistivity multiplied by the temperature (T/λ) of $PrAl_2$ and $LaAl_2$ vs temperature. The third curve is the magnetic part of thermal resistivity of $PrAl_2$

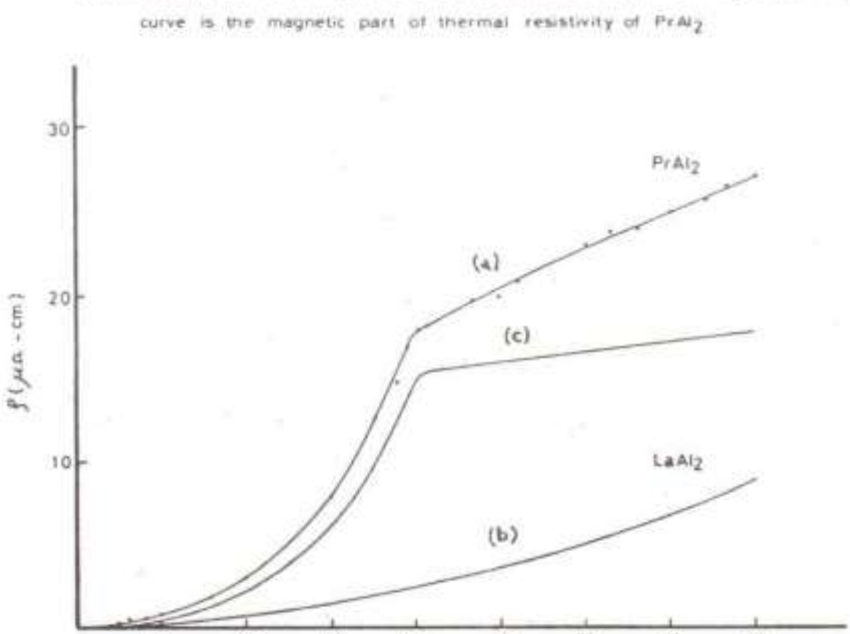

Fig. 2 - Electrical resistivity (ρ) and relative magnetic part curve (c)

which is illustrated curve (1b). Curve (1c) gives the effect of magnetic part of the thermal resistivity of $PrA1_2$, which is obtained by subtracting the values of curve (1b) from those of (la).

For the determination of crystal field Lorentz number, we used the experimental values of the electrical resistivity (ρ) of Bakanowski and Daal [6,7]. To determine the electrical resistivity (ρ) the four-probe technique with copper probes were used. Temperature control was as before. The errors are nearly the same as for the thermal resistivity experiments because the main errors is due to geometrical effects in both cases. Fig. (2) displays the electrical resistivity of $PrA1_2$ and $LaAl_2$ in the temperature range 4.2 K to 80 K. Fig. (2,c), shows the effect of magnetic part of electrical conductivity of $PrA1_2$. The crystal field part of the electrical resistivity differs slightly in the temperatures range 5 K and 40 K, but the difference is clear between 40 K and 80 K.

The thermal and electrical conductivities are the sum of contributions from different electrons scattering process, according to Matthiesen's rule. Since we are interested in the magnetic part of the resistivities from crystal field effects all other contributions such as those from impurity of electron-phonon scattering should be separated. For this purpose the isostructural compound $LaA1_2$ was used as the non-magnetic counter part of $PrA1_2$.

From the magnetic contributions to the thermal and electrical resistivities the crystal field Lorentz number L_{CF} was computed according to the formula :

$$L_{CF} = \frac{P_{CF}}{W_{CF} \cdot T}$$

where W_{CF} is the thermal resistivity .

The values of the relative crystal field Loretnz number are represented in Fig. (3). For metals, where the electrons dominate to the thermal conductivity, the relative Lorentz number L_{CF}/L_o is 12 in so far as

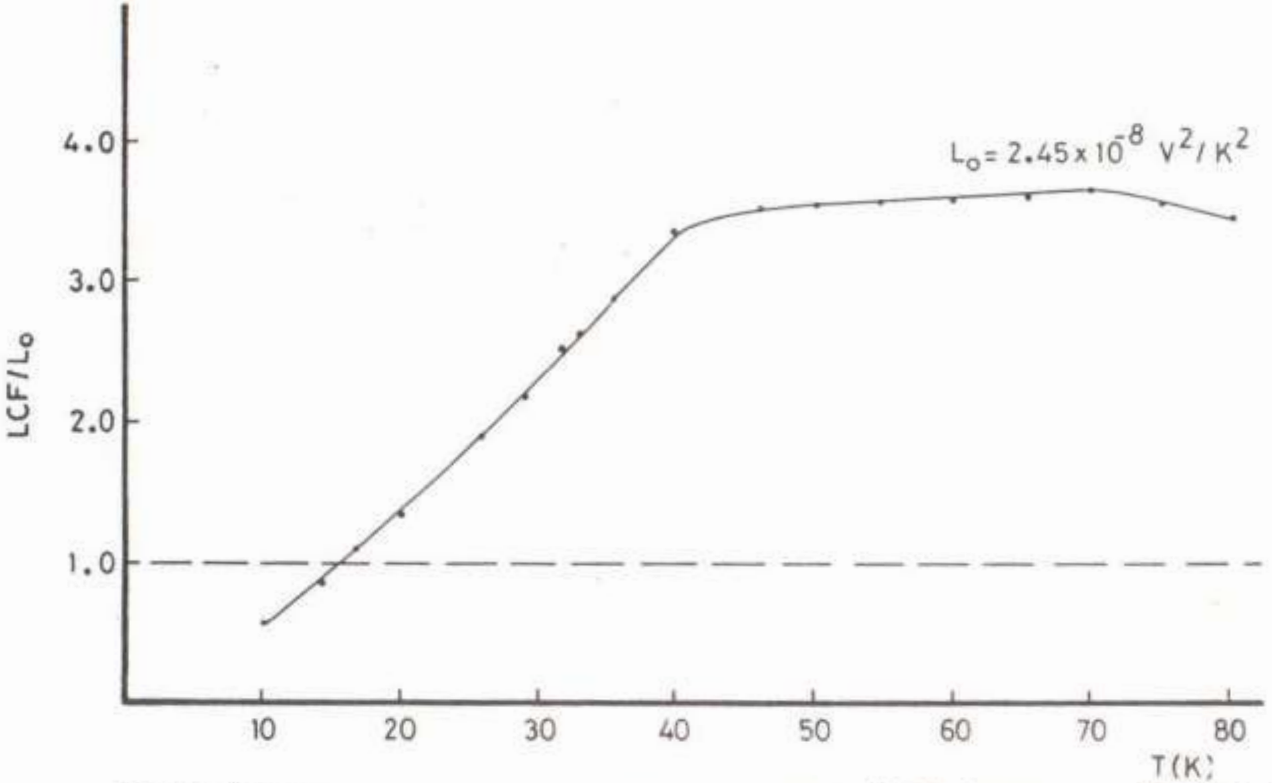

Fig. 3 - Temperature dependence of the crystal field lorenz number for $PrAl_2$

there are only elastic scattering processes [8]. Inelastic scattering processes however, have different effects on the thermal and electrical conductivities, leading to a suppression of Lorentz number. In $\mathrm{PrA1}_{CF}$ the crystal field level scheme has a Γ_1 singlet ground state and an excited Γ_5 state [9, 10]. Because no elastic scattering is possible on Γ_1 level, at low temperature, there is only inelastic scattering (transition $\Gamma_1 - \Gamma_5$) and consequently a low value for L_{CF}/L_o. With increasing temperature the Γ_5 doublet becomes populated In this doublet elastic scattering is possible, so that the Lorentz number increases.

From this analysis of the temperature dependence over the whole temperature range investigated, it was clarified that more than 90% of the thermal resistivity is due to crystal field effects [11,12].

References

1) W. E. Wallace, Rare Earth Intermetallics academic press. New York (1973).
2) Crystal field effect in Metals and alloys, edited by A. Furrer (Plenum, New York 1977), and refences there in.
3) H. Van Veleck, the theory of electric and magnetic susceptibilies (Oxford u.p., Oxford, 1932).
4) S. A. Mahmoud, Ph. D.Thesis, T. U.Dresden (1979).
5) F. Steg;lich, Z. Physik 13. 23 331 (1979).
6) S. Bakanowsi,J. E. Crow, N. F. Berk. T. Mihalisin, Solid State Commun. 17. 111 (1975).
7) H. J. Von Daal. K. H. J. Buschow, solid state commun. 7, 217 (1969).
8) J. M. Ziman, Electrons and phonons, clarendon press. oxford (1963).
9) W. Matz, Dissertation, TU-Dresden (1978).
10) H. G. Purwins, W. J.L. buyers, T. M. Holden, E. C. Svensson in : Magnetism and Magnetic Materils, AIP - Conf. Proc., 29, 259 (1976).
11) Y. H. Wong, Phys. Rev. B17, 3899 (1975).
12) Y. H. Wong and B. Luthi, AIP-Conf. Proc. 29 (1975).